Atmospheric Research 212 (2018) 23–32

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmosres

Joint effects of several factors on cloud-to-ground lightning and rainfall in Nanning (China)

Xiong Li[a,b,*], Ying Pan[c], Zhaoyu Mo[d]

[a] Guangxi Meteorological Observatory, Nanning, People's Republic of China
[b] Key Laboratory of Environment Change and Resources Use in Beibu Gulf, Guangxi Teachers Education University, Ministry of Education, Nanning, People's Republic of China
[c] Guangxi Key Laboratory of Earth Surface Processes and Intelligent Simulation, Guangxi Teachers Education University, Nanning, People's Republic of China
[d] Scientific Research Academy of Guangxi Environmental Protection, Nanning, People's Republic of China

ARTICLE INFO

Keywords:
Lightning
Rainfall
Aerosol
Humidity
Joint effect

ABSTRACT

The data of lightning flash density, total rainfall, surface temperature, surface humidity, convective available potential energy (CAPE) and particulate matter up to 10 μm in size (PM_{10}) over Nanning, China from July 2009 to December 2017 were studied on a yearly/monthly/hourly scale. It was found that the correlation between lightning and precipitation varies in various seasons, and the influencing factors of lightning/precipitation are different in various seasons. CAPE is the most important influencing factor of lightning on an hourly scale. Quantitative analysis showed the joint effects of surface temperature, surface humidity, CAPE and PM_{10} on lightning. For dry cases, lightning increases with increasing PM_{10} for the low value of PM_{10}, and decreases with increasing PM_{10} for the high value of PM_{10}. While the situation is the opposite for wet cases. It was also found that surface temperature and CAPE can affect the correlation between aerosol and lightning.

1. Introduction

Convective activity is one of the most fundamental meteorological events. It plays an important role in atmospheric energetics and hydrological cycle. Lightning activity associated to convective systems is a useful indicator of their rain yield (Hyun et al., 2010). The relation between lightning and convective rain has been shown by the study of visual observations (Battan, 1965), radar observations (Rutledge et al., 1992; Williams et al., 1992), lightning detection network observations (Kucienska et al., 2012; Strader and Ashley, 2014) and satellite observations (SenRoy and BallingJr, 2013; Stolz et al., 2015). Lightning discharges require stronger and deeper uplift, whereas precipitation may occur even at weak and moderate updrafts (Siingh et al., 2015). Positive relation between lightning flash counts and rainfall has been reported in many regions, e.g., Taiwan Island (Liou and Kar, 2010), India (Siingh et al., 2014) and the Pacific coast of southern Mexico (Kucieńska et al., 2012). Cloud-to-ground (CG) lightning can be used in local short term forecasting of heavy rain or in precipitation estimation (Siingh et al., 2014). However, the opposite behavior has been observed between rainfall and lightning flash counts on the global scale for tropical continental centers of rain and lightning range in the opposite order (Price, 2009; Siingh et al., 2013).

Convective activity is formed by buoyancy force controlled primarily by surface air temperature; formation of convective activity is based on thermodynamic conditional instability of the boundary layer, the energy that feeds this process is convective available potential energy (CAPE) (Penki and Kamra, 2013). Higher surface temperature enhances surface heating. This excessive surface heating increases the magnitude of CAPE and its other characteristics in atmosphere, and then invigorates thunderstorm generation (Liou and Kar, 2010). With projections of a warmer climate in the future, how convective activity changes in a warmer world has become one of the key questions related to global warming (IPCC, 2007; Price, 2009).

Aerosol is another important role in regulating convection (Tan et al., 2016; Yuan et al., 2011). Increasing aerosols into atmosphere may reduce solar radiation through scattering, reflection and absorption; then atmospheric instability decreases, which reduces convective strength (Siingh et al., 2014; Siingh et al., 2015). On the other hand, moderate addition of aerosols in polluted regions may result in more cloud condensation nuclei (CCN) and cloud drops, which would invigorate convection (Rosenfeld et al., 2008). Besides, strong updraft, strong instability, greater cloud base height and high aerosol concentration can account for superlative liquid water content in the mixed-phase region, which may result in inverted polarity in thunderstorms; a large ice nuclei concentration may produce dominant positive charge in the lower portion of the mixed-phase region by maintaining

* Corresponding author at: Guangxi Meteorological Observatory, Nanning 530022, People's Republic of China.
E-mail address: lixiong@mail2.sysu.edu.cn (X. Li).

https://doi.org/10.1016/j.atmosres.2018.05.002
Received 2 July 2017; Received in revised form 26 March 2018; Accepted 3 May 2018
0169-8095/

ice saturation (Pawar et al., 2014). In general, aerosol effects can be divided into radiative and microphysical effects (Guo et al., 2016), and play an important role during convective activity forming process, which is mainly regulated by atmospheric humidity (Lal et al., 2018).

Lightning and precipitation, as well as their dependence on various parameters, have been studied by many studies (e.g., Ilotoviz et al., 2016; Lang et al., 2016; Pawar et al., 2017). Lightning and precipitation vary among different stations and among different seasons, while the influences of various factors on lightning/precipitation vary from station to station and from time to time (Siingh et al., 2014; Tinmaker et al., 2016). Further analysis on more stations is needed for better understanding the relation between lightning and precipitation, as well as their dependence on various parameters.

Nanning city is the capital of Guangxi province, South China, which is a subtropical monsoon zone where convective events occur frequently causing one of the largest levels of precipitation and longest duration of flooding in China (Fu and Dan, 2014; Xu et al., 2009). Convective systems in this region are affected by geographical height, SST, tropical cyclones, the atmospheric wind field and the West Pacific Subtropical High, which has been explored by many studies (e.g. Liao et al., 2015; Yuan et al., 2014; Zhong and Chen, 2015). However, no paper, to our knowledge, has examined the relation between lightning and precipitation in Nanning, as well as its dependence on meteorological factors. Therefore, this paper focuses on Nanning and (1) studies the relation of lightning and precipitation; (2) investigates the effects of surface temperature, CAPE, particulate matter up to 10 μm in size (PM_{10}) and surface humidity on both lightning and precipitation; (3) analyses the interaction of these effects.

2. Dataset and methodology

Nanning city, the capital of Guangxi province, is the area studied (Fig. 1). It has an area of 6, 476 km^2 with about 2.6 million inhabitants. The data, including meteorological data, lightning flashes data and PM_{10} concentration data, are from July 2009 to December 2017.

The meteorological data, including total rainfall, surface temperature, surface humidity and CAPE data, were obtained form Nanning weather station (longitude 108.35°E,latitude 22.82°N, altitude 121.6 m, World Meteorological Organization ID code: 59431). It has a subtropical monsoon climate with an annual average temperature of 21.8 °C, an annual rainfall of 1, 310 mm, and an annual sunshine duration of 1, 585 h. The data of surface temperature, rainfall and surface humidity were observed at surface once an hour. The data of CAPE was based on the sounding data and was calculated pseudo adiabatically from temperature and relative humidity fields on 8 vertical pressure levels (1000/925/850/700/500/400/300/200 mb), which was observed only at 08 and 20 LST (LST = UTC + 8 h), while hourly CAPE in other hours was calculated by interpolation using the data in 08 and 20 LST.

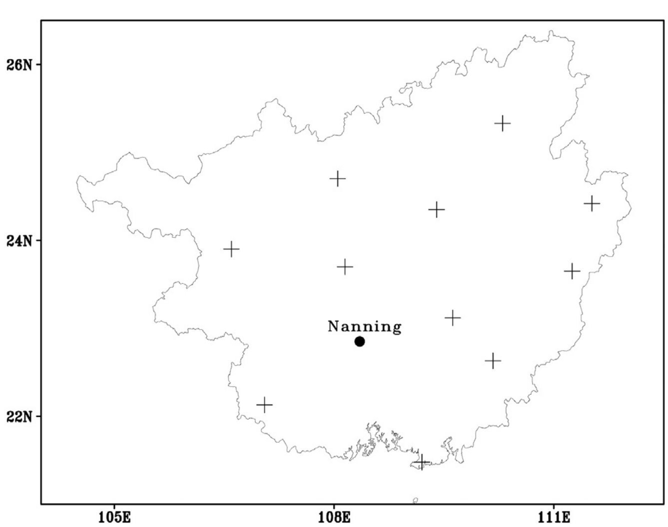

Fig. 1. Map of Guangxi province, China showing the study region for the present study: Nanning. The locations of 11 lightning sensors are shown by plus signs.

The hourly lightning flashes data were obtained from Guangxi meteorological bureau. It was observed by a local lightning monitoring system. This represents a province-wide lightning detection (LD) network consisting of 11 lightning sensors to provide the coverage of lightning flashes for the entire Guangxi province (Fig. 1). The CG lightning detection efficiency and median error of the location accuracy are above 90% and < 1 km, respectively. It uses the Improved Performance through Combined Technology (IMPACT) method, which combines the direction finding and time of arrival technology to determine the lightning location. A spatial scale of 0.1° latitude × 0.1° longitude (about 100 km^2) surrounding the weather station was selected to find out the CG lightning flash counts following Liou and Kar (2010). Lightning flash density, which is defined as the number of flashes, is used to describe lightning activity. Following the previous papers (e.g., Zheng et al., 2016), + CG lightning with current < 0 kA was removed from the dataset because it could be a misinterpretation of cloud lightning.

The daily PM_{10} concentration data were obtained from Nanning environmental protection bureau. It was reported that PM_{10} concentration is better than aerosol optical depth (AOD) for studying the aerosol effect on precipitation because the former could be observed under all-sky conditions while the latter is measurable only under cloud-free conditions and gives no information about where aerosols reside in the vertical column; besides, PM_{10} has a close relation with $PM_{2.5}$ (particulate matter up to 2.5 μm in size) and is sufficient for studying the radiative and microphysical effects of aerosols on convective systems over South China (Guo et al., 2016). Thus, ground measurement of PM_{10} concentration data rather than AOD data was chosen as a proxy for CCN in this study.

The data have undergone quality control checks at Guangxi meteorological bureau and Nanning environmental protection bureau. Data availability is above 99.5% for the variables total CG flashes, + CG flashes, rainfall, surface temperature, surface humidity and CAPE, and is above 97% for the variable PM_{10} concentration.

Following the previous papers (Liou and Kar, 2010; Tan et al., 2016), the parameters P_{+CG} and rain yield were computed as following.

$$P_{+CG} = \frac{\text{number of positive CG flash counts during a certain time period}}{\text{number of total CG flash counts over the same time period}} \tag{1}$$

$$\text{Rain yield} = \frac{\text{rainfall during a certain time period}}{\text{number of total CG flash counts over the same time period}} \tag{2}$$

where "a certain time period" is a year, a month or an hour respectively. However, rain yield will not be analyzed on an hourly scale for a significant lag was reported between diurnal cycles of lightning and rainfall (Price, 2013).

3. Results

3.1. Annual variation

The annual variations of total CG flashes, P_{+CG}, total rain, rain yield, surface temperature, CAPE, PM_{10} and surface humidity are presented in Fig. 2. When surface temperature decreases from 2010 to 2011, total CG flashes decreases at the same time. Moreover, both of them increase from 2011 until reaching peaks in 2016, and then decrease in 2017. The trends of CAPE and surface humidity are similar to those of surface temperature/total CG flashes except that peak is in